

AFRL-AFOSR-UK-TR-2012-0021



X-ray Observations of the Sun: Solar Flares and their Impact on the Geophysical Space

Professor Michele Piana

**Universita' di Genova
Dipartimento Di Matematica
Via Dodecaneso 35
Genova, Italy 16146**

EOARD Grant 09-3050

Report Date: July 2012

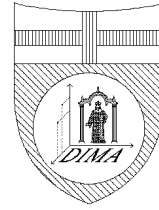
Final Report from 15 April 2009 to 14 April 2010

Distribution Statement A: Approved for public release distribution is unlimited.

**Air Force Research Laboratory
Air Force Office of Scientific Research
European Office of Aerospace Research and Development
Unit 4515 Box 14, APO AE 09421**

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
<p>Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</p> <p>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</p>					
1. REPORT DATE (DD-MM-YYYY) 25 July 2012		2. REPORT TYPE Final Report		3. DATES COVERED (From – To) 15 April 2009 – 14 April 2010	
4. TITLE AND SUBTITLE X-ray Observations of the Sun: Solar Flares and their Impact on the Geophysical Space				5a. CONTRACT NUMBER FA8655-09-1-3050	
				5b. GRANT NUMBER Grant 09-3050	
				5c. PROGRAM ELEMENT NUMBER 61102F	
				5d. PROJECT NUMBER	
6. AUTHOR(S) Professor Michele Piana				5d. TASK NUMBER	
				5e. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Universita' di Genova Dipartimento Di Matematica Via Dodecaneso 35 Genova, Italy 16146				8. PERFORMING ORGANIZATION REPORT NUMBER N/A	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) EOARD Unit 4515 BOX 14 APO AE 09421				10. SPONSOR/MONITOR'S ACRONYM(S) AFRL/AFOSR/RSW (EOARD)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S) AFRL-AFOSR-UK-TR-2012-0021	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT <p>The aim of the present project was to apply computational tools based on the theory and practice of inverse problems for inferring information on the dynamical processes occurring during solar flares. More precisely, we processed hard X-ray counts provided by the NASA satellite RHESSI (Reuven Ramaty High Energy Solar Spectroscopy Imager), on orbit since February 2002, in order to reconstruct images of the flaring electron distribution in the solar chromosphere at different energies, within an imagingspectroscopy framework. Specifically, the project focused on: • the formulation and validation of a regularization procedure which allowed the synthesis of electron maps at different electron energies from calibrated measurements, called visibilities, of specific spatial Fourier components of the source distribution; • the application of such a methodology to RHESSI data sets recorded during events of different magnitude and topography together with a rigorous statistical interpretation of the results.</p> <p>The main results of the project have been collected in the following papers: 1) Prato M, Piana M, Emslie A G, Hurford G J, Kontar E P and Massone A M 2009 A regularized visibilitybased approach to astronomical imaging spectroscopy SIAM J. Imaging. Sci. 2 910-930: in this paper we provide the mathematical foundation of a new approach to imaging spectroscopy, in which electron maps smoothed along the electron energy direction are reconstructed from the X-ray visibility observed by the Reuven Ramaty High Energy Solar Spectroscopy Imager (RHESSI). 2) Massone A M, Emslie A G, Hurford G J, Prato M, Kontar E P and Piana M 2009 Hard X-ray imaging of solar flares using interpolated visibilities Astrophys. J. 703 2004-2016: in this paper we describe a new imaging technique for the reconstruction of hard X-ray images from hard X-ray visibilities recorded by rotating modulation collimators. Further, we applied this imaging technique to real observations provided by RHESSI. 3) Prato M, Emslie A G, Kontar E P, Massone A M and Piana M 2009 The location of centroids in photon and electron maps of solar flares Astrophys. J. 706 917-922: using the regularized electron maps, in this paper we infer information about the energy transport processes occurring during solar flares. 4) Massone A M and Piana M The use of electron maps to constrain some physical properties of solar flares Sol. Phys. (in press): this paper describes a general framework within which the regularized electron maps can be utilized in order to select the most reliable model of energy transport for a given flaring event.</p> <p>In the framework of the project we also implemented two Interactive Data Language (IDL) software packages realizing the reconstruction of hard X-ray images and of regularized electron maps from RHESSI hard X-ray visibilities. Such packages are now at disposal of the solar physics community within the SolarSoftWare (SSW) tree. Finally, during the project we organized the 9th RHESSI workshop which took place in Genova, Italy, in Sep 2009.</p>					
15. SUBJECT TERMS EOARD, Space Weather, Solar Monitoring					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 4	19a. NAME OF RESPONSIBLE PERSON SCOTT DUDLEY, Lt Col, USAF
a. REPORT UNCLAS	b. ABSTRACT UNCLAS	c. THIS PAGE UNCLAS			19b. TELEPHONE NUMBER (Include area code) +44 (0)1895 616162

Universita' di Genova
DIPARTIMENTO DI MATEMATICA
Via Dodecaneso 35
16146 Genova (Italia)
Tel.: (010)3536751
Fax: (010)3536752



Title of the project: X-ray observations of the Sun: solar flares and their impact on the geophysical space

Coordinator: Michele Piana, Dipartimento di Matematica, Università di Genova

Scientific Report

The aim of the present project was to apply computational tools based on the theory and practice of inverse problems for inferring information on the dynamical processes occurring during solar flares. More precisely, we processed hard X-ray counts provided by the NASA satellite RHESSI (Reuven Ramaty High Energy Solar Spectroscopy Imager), on orbit since February 2002, in order to reconstruct images of the flaring electron distribution in the solar chromosphere at different energies, within an imaging-spectroscopy framework. Specifically, the project focused on:

- the formulation and validation of a regularization procedure which allowed the synthesis of electron maps at different electron energies from calibrated measurements, called visibilities, of specific spatial Fourier components of the source distribution;
- the application of such a methodology to RHESSI data sets recorded during events of different magnitude and topography together with a rigorous statistical interpretation of the results.

The main results of the project have been collected in the following papers:

1) Prato M, Piana M, Emslie A G, Hurford G J, Kontar E P and Massone A M 2009 A regularized visibility-based approach to astronomical imaging spectroscopy SIAM J. Imaging. Sci. 2 910-930: in this paper we provide the mathematical foundation of a new approach to imaging spectroscopy, in which electron maps smoothed along the electron energy direction are reconstructed from the X-ray visibility observed by the Reuven Ramaty High Energy Solar Spectroscopy Imager (RHESSI).

2) Massone A M, Emslie A G, Hurford G J, Prato M, Kontar E P and Piana M 2009 Hard X-ray imaging of solar flares using interpolated visibilities Astrophys. J. 703 2004-2016: in this paper we describe a new imaging techniques for the reconstruction of hard X-ray images from hard X-ray visibilities recorded by rotating modulation collimators. Further, we applied this imaging techniques to real observations provided by RHESSI.

3) Prato M, Emslie A G, Kontar E P, Massone A M and Piana M 2009 The location of centroids in photon and electron maps of solar flares *Astrophys. J.* 706 917-922: using the regularized electron maps, in this paper we infer information about the energy transport processes occurring during solar flares.

4) Massone A M and Piana M The use of electron maps to constrain some physical properties of solar flares *Sol. Phys.* (in press): this paper describes a general framework within which the regularized electron maps can be utilized in order to select the most reliable model of energy transport for a given flaring event.

In the framework of the project we also implemented two Interactive Data Language (IDL) software packages realizing the reconstruction of hard X-ray images and of regularized electron maps from RHESSI hard X-ray visibilities. Such packages are now at disposal of the solar physics community within the SolarSoftWare (SSW) tree.

Finally, during the project we have also organized the 9th RHESSI workshop which took place in Genova, Italy, in September 2009.